

(19)



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Office européen des brevets



(11)

EP 0 806 476 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
12.11.1997 Bulletin 1997/46

(51) Int Cl.⁶: **C12N 1/10, C12N 9/02**
// A61K35/68, C07K14/44

(21) Application number: **97303085.1**

(22) Date of filing: **06.05.1997**

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC
NL PT SE

(30) Priority: **06.05.1996 US 643751**

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(54) **Attenuated strains of leishmania and uses thereof**

(57) Attenuated strains of *Leishmania* are provided in which at least one gene contributing to virulence of the strain and expressed in both the promastigote and amastigote forms of the strain is functionally disabled,

such as, by deleting at least a portion of the gene or by mutagenesis of the gene. The attenuated strain may be used for administration to a host to confer protection against disease caused by a virulent *Leishmania* strain or as a diagnostic reagent.

EP 0 806 476 A2

Description**FIELD OF INVENTION**

5 The present invention relates to the field of molecular immunobiology and in particular to immunogenic preparations including vaccines comprising attenuated strains of *Leishmania*.

BACKGROUND OF INVENTION

10 Parasitic protozoa of the order Kinetoplastidae are the causative agents of several tropical diseases including sleeping sickness by *Trypanosoma brucei*, Chagas by *Trypanosoma cruzi*, visceral (kala-azar) and cutaneous (oriental sore) Leishmaniasis by *Leishmania donovani* and *Leishmania major* respectively. In particular *Leishmania* protozoans are the causative agents of human leishmaniasis, which includes a spectrum of diseases ranging from self-healing skin ulcers to fatal visceral infections. Human leishmaniasis is caused by at least thirteen different species and sub-
 15 species of parasites of the genus *Leishmania*. Leishmaniasis has been reported from about eighty countries and probably some 400,000 new cases occur each year. Recently the World Health Organization has reported 12 million people to be infected (ref. 1. Throughout this application various references are referred to in parenthesis to more fully describe the state of the art to which this invention pertains. Full bibliographic information for each citation is found at the end of the specification, immediately preceding the claims. The disclosure of these references are hereby incorporated by
 20 reference into the present disclosure. A listing of the references appears at the end of the disclosure).

Untreated visceral leishmaniasis is usually fatal and mucocutaneous leishmaniasis produces mutilation by destruction of the naso-oropharyngeal cavity and, in some cases, death.

In addition a major health problem has been created in areas of high infection when blood is collected for transfusion purposes. Since blood is a carrier of the parasites, blood from an infected individual may be unknowingly transferred
 25 to a healthy individual.

The *Leishmania* protozoans exist as extracellular flagellated promastigotes in the alimentary tract of the sandfly in the free-living state, and are transmitted to the mammalian host through the bite of the insect vector. Once introduced, the promastigotes are taken up by macrophages, rapidly differentiate into non-flagellated amastigotes and start to multiply within the phagolysosomal compartment. As the infected cells rupture, amastigotes subsequently infect other
 30 macrophages giving rise to the various symptoms associated with leishmaniasis (refs. 1 and 2).

Leishmaniasis is, therefore, a serious disease and various types of vaccines against the disease have been developed, including live parasites; frozen promastigotes from culture; sonicated promastigotes; gamma-irradiated live promastigotes; and formalin-killed promastigotes treated with glucan (reviewed in, for example ref. 3). However, none of these approaches have provided efficacious vaccines.

35 Trypanosomatids, among many other metabolic peculiarities, maintain the redox balance of the cell by a mechanism that is completely different from that of their mammalian host. They lack glutathione reductase which in nearly all organisms is responsible for the maintenance of an intracellular reducing environment important for the reduction of disulphides, the detoxification of peroxides and the synthesis of DNA precursors (refs. 4 and 5). Instead, they possess a unique system using as a main thiols, the *N*2, *N*8-bis(glutathionyl)spermidine, also named trypanothione [T(SH)₂] and the monogluthionyl spermidine. These conjugates are kept in the reduced state by trypanothione reductase (TR) (refs. 4, 6 and 7). TR is a member of a NADPH-dependent flavoprotein oxidoreductase family and it is structurally and mechanistically related to the human glutathione reductase (GR) (refs. 6 and 8).

45 *Leishmania*, during its infective cycle, must survive the rigours of the host's oxidative phagocytic macrophages producing toxic oxygen intermediates. TR and thiols play a vital role in maintaining an intracellular reducing environment and in protecting these parasites against oxidative damage, arising both internally as a result of their aerobic metabolism and externally by the immune response of the mammalian host (refs. 4 and 6).

Leishmania infection may lead to serious disease. It would be advantageous to provide attenuated strains of *Leishmania* and methods of production thereof, for use as antigens in immunogenic preparations, including vaccines, and the generation of diagnostic reagents.

SUMMARY OF THE INVENTION

55 The present invention is directed towards the provision of attenuated strains of *Leishmania*. The attenuated strains are useful for the preparation of immunogenic preparations including vaccines against disease caused by infection by a virulent *Leishmania* strain and as tools for the generation of immunological and diagnostic reagents.

In accordance with one aspect of the present invention, there is provided an attenuated strain of *Leishmania* wherein at least one gene of the strain contributing to virulence thereof and expressed in both the promastigote and amastigote stages of the life cycle of the strain has been functionally disabled by, for example, a deletion of at least a

portion of the gene or by mutagenesis.

In another aspect of the invention, there is provided an attenuated strain of *Leishmania* wherein both wild-type copies of a gene of the strain contributing to virulence thereof have been functionally disabled and a third copy of the wild-type gene is present in the chromosome of the strain. The gene contributing to the virulence of the strain in this aspect of the invention may be one expressed in both the promastigote and amastigote stages of the life cycle of the strain.

The gene may contribute to the ability of the strain to infect or survive within macrophages and, in a particular embodiment, may encode trypanothione reductase. The attenuated *Leishmania* strain may be selected from the group consisting of *Leishmania donovani*, *Leishmania braziliensis*, *Leishmania tarentolae*, *Leishmania major*, *Leishmania mexicana*, *Leishmania tropica* and *Leishmania aethiopica*.

In a further aspect, the present invention provides an immunogenic composition comprising the attenuated strains as provided herein. The immunogenic composition may be formulated as a vaccine for *in vivo* administration to a host, such as a primate including humans, to confer protection against disease caused by a virulent strain of *Leishmania*, including *Leishmania donovani*, *Leishmania braziliensis*, *Leishmania tarentolae*, *Leishmania major*, *Leishmania mexicana*, *Leishmania tropica* and *Leishmania aethiopica*.

In an additional aspect, the invention provides a method of generating an immune response in a host, such as, a primate including humans, comprising administering thereto an immunoeffective amount of the immunogenic composition, as provided herein. In a particular aspect, the immunogenic composition may be formulated as a vaccine for *in vivo* administration to the host to confer protection against disease caused by a virulent strain of *Leishmania*, including *Leishmania donovani*, *Leishmania braziliensis*, *Leishmania tarentolae*, *Leishmania major*, *Leishmania mexicana*, *Leishmania tropica* and *Leishmania aethiopica*.

In yet an additional aspect, there is provided a method for producing a vaccine for protection against a disease caused by infection by a virulent strain of *Leishmania*, including *Leishmania donovani*, *Leishmania braziliensis*, *Leishmania tarentolae*, *Leishmania mexicana*, *Leishmania tropica* and *Leishmania aethiopica*, and comprising administering the immunogenic composition as provided herein to a test host to determine an amount and frequency of administration thereof to confer protection against disease caused by infection by the *Leishmania* parasite and formulating the immunogenic composition in a form suitable for administration to a treated host, including humans, in accordance with said determined amount and frequency of administration.

In a further aspect of the invention, there is provided a method of forming an attenuated strain of *Leishmania*, which comprises identifying a gene of a *Leishmania* strain contributing to the virulence thereof and expressed in both the promastigote and amastigote stages of the life cycle of the strain, and functionally disabling the gene.

These virulence genes may be functionally disabled by, for example, deletion or mutation, including insertional mutagenesis and, furthermore, the wild-type *Leishmania* gene may be replaced by the functionally disabled gene. The virulence genes may be functionally disabled by, for example, replacing the gene by a selectable antibiotic resistance gene by homologous recombination following transformation of the *Leishmania* organism with a fragment of DNA containing the antibiotic resistance gene flanked by 5'- and 3'- noncoding DNA sequences.

This method can be used to generate the attenuated variants of *Leishmania* and the residual pathogenicity of the attenuated variants can be assessed in mice and hamsters. Deletion of the genes that are selectively expressed results in an attenuated strain which cannot survive in humans but generates a protective immune response. Attenuated strains of *Leishmania* as provided herein would be useful as live vaccines against the diseases caused by *Leishmania*.

Advantages of the present invention include the provision of safe and attenuated strains of *Leishmania* for the preparation of immunogenic compositions including vaccines and for the generation of immunological and diagnostic reagents.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be further understood from the following description and specific Examples with reference to the Figures, in which:

Figure 1(A) shows schematically the inactivation of the two copies of the trypanothione reductase gene in *Leishmania donovani*;

Figure 1(B) shows a Southern blot analysis of wild-type *Leishmania donovani* and strains having one or two of the trypanothione reductase genes deleted therefrom;

Figure 1(C) shows a molecular karyotype of diploid and triploid *Leishmania donovani* trypanothione reductase gene transfectants;

Figure 2(A) shows schematically the inactivation of trypanothione reductase gene in *Leishmania tarentolae*;

Figure 2(B) shows a Southern blot analysis of wild-type *Leishmania tarentolae* and strains having one or two copies of the trypanothione reductase gene deleted therefrom;

Figure 2(C) shows a molecular karyotype of diploid and triploid *Leishmania tarentolae* trypanothione reductase gene transfectants;

Figure 3(A) is a CHEF blot of chromosomes of the diploid and triploid *TR L. tarentolae* transfectants hybridizing to *TR*, *neo* and *hyg* probes;

Figure 3(B) shows the integration of the I-SceI recognition sequence into *TR* gene together with a *neo* expression cassette;

Figure 3(C) shows, the generation of the third *TR* allele in triploid *L. tarentolae* mutant;

Figure 4 is a Northern blot to show trypanothione reductase mRNA expression in wild-type and *Leishmania donovani* trypanothione reductase inactivated mutants;

Figure 5, comprising panels A and B, shows the ability of *Leishmania donovani* trypanothione reductase disrupted mutants to infect human macrophages;

Figure 6(A) shows a Southern blot of the deletion of the trypanothione reductase gene from *Leishmania major* by gene targeting; and

Figure 6(B), consisting of two panels, shows the ability of *Leishmania major* trypanothione reductase inactivated mutants to infect human macrophages.

GENERAL DESCRIPTION OF THE INVENTION

Referring to Figure 1, there is schematically illustrated the inactivation of trypanothione reductase (TR) genes in *Leishmania donovani*. The *TR* gene is a single copy gene in the *Leishmania* genome and it is located on a 520 kb chromosome (ref. 9, 1994; Fig 1C). Since the *Leishmania* genome is diploid and no sexual crosses have been achieved, two successive rounds of gene targeting are necessary to disrupt such a single copy gene. To inactivate both alleles of the *TR* gene of *L. donovani* by gene disruption mediated by homologous recombination, a 1.2 kb fragment entirely within the *TR* coding sequence was amplified by PCR. This fragment was inserted into pSP72 vector. The neomycin phosphotransferase (*neo*) and the hygromycin phosphotransferase (*hyg*) expression cassettes (ref. 10) were introduced into the unique *BalI* site of the *TR* gene, at 387 bp from the 3'-end of the PCR generated fragment (see Fig. 1A). In a first round of targeting, the *TR-hyg* replacement construct was transfected into *L. donovani*. Cells growing in the presence of hygromycin B were cloned on semi-agar plate and the DNA of clones were digested with *XhoI* and analyzed by Southern blots hybridized to specific *TR* and *hyg* probes (see Figure 1(B)). A schematic drawing of the *TR* locus in *L. donovani* with the *TR* gene and restriction sites (*X*, *XhoI*, *B1*, *BalI*) is shown in Figure 1(A). Upon integration of the *hyg* or *neo* genes at the homologous locus, the genomic 8 kb *XhoI* fragment would increase to 9.2 kb and to 8.9 kb, respectively. The 3.5 kb *X-X'* corresponds to a new restriction fragment generated following genomic rearrangements to translocation of a part of the *TR* locus on a 1200 kb chromosome.

Figure 1(B) shows a Southern blot analysis of *L. donovani* WT and *TR* single and double replacement mutants. DNAs were digested with *XhoI*, electrophoresed through an agarose gel and hybridized independently with *TR*, *hyg* and *neo* specific probes. Lanes 1, *L. donovani* WT strain; 2, *L. donovani TR/hyg* single knockout strain and 3, *L. donovani TR/hyg/neo* double targeted mutant. Two *XhoI* fragments of 7 and 8 kb are recognized by the *TR* probe in wild type (WT) *L. donovani* (Fig. 1(A) and 1(B), lane 1). Upon the integration of the *hyg* gene into the *TR* locus the 8 kb restriction band increased by 1.2 kb to yield a 9.2 kb fragment whereas the 7 kb fragment remained unchanged. The presence of a 8 kb band in these clones corresponds to the second non-targeted *TR* allele (Fig. 1(B), lane 2). Further hybridization of the 9.2 kb fragment to a *hyg* probe (Fig. 1(B), lane 2) confirmed the presence of the expected heterozygous replacement.

A clone of the *TR/hyg* transfectant was then used for the second round of targeting using the *TR-neo* replacement construct (Fig. 1(A)). Transfectants resistant to G418 and hygromycin B were obtained and clones were analyzed by hybridization using probes specific for *TR*, *neo* and *hyg*. The *neo* gene was integrated into the *TR* locus as an *XhoI* fragment of the expected size of 8.9 kb was obtained following hybridization to a *neo* probe (see Fig. 1(B), lane 3). Although the *neo* and *hyg* replacements took place as expected, one *TR* allele remained intact since the genomic 8 kb *XhoI* fragment was also present in the double targeted mutant (Fig. 1(B), lane 3). Moreover, a novel 3.5 kb *XhoI*-fragment hybridizing to the *TR* probe was detected in this transfectant (Fig. 1(B), plane 3) indicating that this novel band is a result of genomic rearrangements that occurred relatively close to the *TR* gene.

To look at how this novel fragment has arisen, chromosomes of the *TR/hyg/neo* transfectant were resolved by CHEF electrophoresis and the blot was hybridized with the appropriate probes. In Figure 1(C), there is shown a molecular karyotype of diploid and triploid *L. donovani TR* transfectant. Chromosomes were separated by pulsed-field gel electrophoresis using a Biorad CHEF-DR III apparatus at 5 V/cm, 120° separation angle and switch times varying from 35-120 for 27 h. Lanes 1: *L. donovani* WT strain; 2: *L. donovani TR/hyg* single knockout strain; and 3: *L. donovani TR/hyg/neo* double targeted mutant. Blots were hybridized with *TR*, *hyg* and *neo*-specific probes as shown. In addition to a 520 kb chromosome on which the *TR* gene is normally located, a new chromosome of approximately 1200 kb hybridized to a *TR* specific probe (Fig. 1(C), lane 3). The third allele present in the new chromosomal location correspond

to the one targeted by the *neo* gene (see Fig. 1(C), lane 3), thus leaving an intact *TR* allele in the initial chromosomal location (520 kb). Therefore this attempt to generate a *TR* null mutant in *L. donovani* has failed and, in an additional independent transfection, we were also unable to generate a null mutant as the locus became triploid. This may suggest that the *TR* gene is an essential gene. To test whether the polyploidy of the *TR* locus occurred only in a pathogenic virulent strain as previously described for the *dhfr-ts* gene of one virulent *L. major* strain (ref. 11), we have attempted to disrupt the *TR* gene of the non-pathogenic lizard strain *L. tarentolae*. Thus, referring to Figure 2, there is schematically illustrated the inactivation of the *TR* gene in *Leishmania tarentolae*. Constructs derived from one species are not appropriate for the targeting of genes of another species of *Leishmania*. Therefore, the *TR* gene of *L. tarentolae* was amplified by PCR and the *hyg* and *neo* expression cassettes were cloned into the *Bal*I site of the PCR fragment and transfections were performed to inactivate both alleles of the *L. tarentolae* *TR* gene. Referring to Figure 2A there is a schematic drawing of the *TR* locus in *L. tarentolae*. Following integration of the *hyg* gene at the homologous locus, two additional *Eco*RI (RI) fragments of 8.75 and 3.8 kb would be generated and after the *neo* insertion two *Eco*RI fragments of 8.5 and 3.8 kb.

Figure 2(B) shows a Southern blot analysis of WT, single targeted and double targeted *TR* *L. tarentolae* mutants. DNAs were digested with *Eco*RI, electrophoresed through an agarose gel and hybridized with *TR*, *hyg* and *neo* specific probes. Lanes 1: *L. tarentolae* TarII WT strain 2: *L. tarentolae* *TR/hyg* and 3: *L. tarentolae* *TR/hyg/neo*. Disruption of one *TR* allele, by replacement with a *TR-hyg* fragment, led to the generation of two expected additional *Eco*RI bands of 8.75 and 3.8 kb as well as the intact allele of 11.5 kb is indicated by Southern blot analysis of transfectant's DNA hybridized to *TR* and *hyg* probes (Fig. 2(B), lane 2). Upon integration of the *TR-neo* construct into the remaining intact *TR* allele of the *L. tarentolae* *TR/hyg* strain, the expected *Eco*RI fragments of 8.5 and 3.8 kb hybridized to the *TR* probe and only the 3.8 kb band hybridized to the *neo* probe as expected but nevertheless one *TR* allele was present (Fig. 2(B), lane 3). Two further independent transfections into *L. tarentolae* ended up also with a *TR* triploidy. Contrary to *L. donovani*, no additional bands hybridizing to *TR* observed, and both disrupted and wild type *TR* alleles were located on a same chromosome of the same size (Fig. 2(C)).

To exclude the possibility of preexisting triploidy of the *TR* gene in *L. tarentolae* and to map the third *TR* allele with respect to the *TR* normal chromosomal location we have integrated into the *TR* locus a *neo* cassette containing a unique sequence corresponding to the recognition site of I-SceI endonuclease. Referring to Figure 3, there is shown the integration of the endonuclease I-SceI into the *TR* locus to explain *TR* triploidy in *L. tarentolae*. Figure 3A shows a CHEF blot of chromosomes of the diploid and triploid *TR* *L. tarentolae* transfectants hybridizing to *TR*, *neo* and *hyg* probes. Upon digestion with the I-SceI endonuclease, three chromosomal fragments would be generated as shown in Lanes 1: *L. tarentolae* WT 2: *TR/neo-SceI* digested with endonuclease I-SceI 3: and *TR/hyg/neo-SceI* digested with I-SceI. I-SceI has an 18-bp recognition sequence (ref. 22). Following digestion of the single *TR/neo* knockout transfectant with the endonuclease I-SceI the 520 kb chromosome was fragmented in two pieces one of 150 and the second of 370 kb as detected by hybridization of a CHEF blot with the *TR* probe (Fig. 3(A), lane 2). Only the largest fragment of 370 kb hybridized to a *neo* probe as expected. In Figure 3(B), there is illustrated a schematic drawing of the integration of the I-SceI recognition sequence into the *TR* gene together with a *neo* expression cassette. Following I-SceI digestion three fragments should be generated; one of 520 kb corresponding to the intact *TR* carrying chromosome and two fragments resulted from the *in vitro* fragmentation of the second chromosomal allele within the unique I-SceI integration. Figure 3(C) shows the generation of the third *TR* allele in the triploid *L. tarentolae* mutant supported by the results of the I-SceI digest. A region of approximately 30 kb was duplicated providing the *TR* triploidy. This increased the size of the two I-SceI chromosomal fragments to 160 and 390 kb, respectively, instead of 150 and 370 kb as shown in panel B. In a double targeted mutant where one *TR* allele was disrupted by *hyg* and the second by the *neo*-I-SceI cassette two fragments of slightly different sizes of 160 and 390 kb were hybridized to a *TR* probe (Fig. 3(A), lane 3 and Fig. 3(C)) indicating that approximately 30 kb were added in the *neo* targeted chromosome during rearrangement leading to the *TR* polyploidy.

The single and double targeted *TR* mutants generated by gene disruption described herein contained one intact *TR* allele. To examine the effect of the decrease in *TR* copy number to *TR* expression, mRNA levels in both promastigote and amastigote stages of the parasite were examined. Figure 4 shows *TR* mRNA expression in the control and *TR* single and double *L. donovani* targeted mutants. In Figure 4(A) total RNAs isolated from the promastigote and amastigote stages of *L. donovani* control and transfectants were hybridized with a *TR* specific probe. Each track contained 5 µg of RNA. Lanes 1, *L. donovani* WT; 2, *TR/hyg* single knockout and 3, *TR/hyg/neo* double targeted mutant. In Figure 4(B), the same blot was stripped off and re-hybridized with the *T. brucei* α -tubulin probe to monitor the amount of RNA layered on each lane. This Northern blot analysis using a *TR* specific probe showed that *L. donovani* parasites either with the *TR/hyg* or the *TR/hyg/neo* background have much lower RNA levels compared to the WT (Fig. 4(A)). No differential expression of *TR* in the mutants was noted between promastigotes and amastigotes (see Fig. 4(A)). The amastigote's total RNA was checked by hybridization with an amastigote specific probe, the gene A2 (ref. 12). The amount of RNA loaded was compared with a tubulin probe (Fig. 4(B)).

To determine whether decreased levels of mRNA in the disruption mutants correlated with decreased *TR* activity

we have measured enzymatic activities in control and *TR* mutant strains. A significant decrease on *TR* enzymatic activity was detected in the single and the double targeted *TR* mutants as shown in Table I. Reduced *TR* activity did not affect the growth of *Leishmania* in culture media and did not influence the transformation to amastigotes *in vitro*. In *L. donovani TR/hyg* and *TR/hyg/neo* targeted mutants, the *TR* activity was 2.7-fold lower than in control *L. donovani* WT cells (Table 1). A 4-fold decrease in *TR* activity was detected in the *L. tarentolae TR/hyg/neo* transfectant (see Table 1). The ability of the *TR*-disruption mutants to survive within human macrophages was examined using an *in vitro* infection system. Both the single *L. donovani TR/hyg* and the double targeted *TR/hyg/neo* mutants were tested. Figure 5 shows the infectivity of *L. donovani TR* replacement mutants toward human macrophages. Cells from stationary phase of *L. donovani* control and the single and double *TR* replacement mutants were harvested and counted with the Neubauer improved counting chamber. Human macrophages (5×10^4 cells/well) were incubated with *Leishmania* parasites (20:1, parasite-to-cell ratio) for 6 hours. After this initial incubation, free parasites were washed and fresh media was added to the wells and incubated for 24, 48 and 72 hours. At these fixed time points cell cultures were dried and stained with Diff Quick in order to determine the level of infection. The panel in Fig. 5(B) corresponds to the total number of amastigotes in 100 macrophage cells and the panel in Fig. 5(A) to the percentage of infected macrophages with time. ■ *L. donovani-neo* (control strain with a plasmid carrying the *neo* gene); ○ *L. donovani TR/hyg*, △ *L. donovani TR/hyg/neo*, □ *L. donovani TR/neo + TR*. The average and standard deviation of four independent experiments are shown. The intracellular survival of the amastigotes of the *L. donovani TR/hyg* and *TR/hyg/neo* mutants inside human monocytes differentiated to macrophages was measured by microscopic examination after 24, 48 and 72 hours post-infection and compared to *L. donovani* transfected with a *neo*-containing plasmid as a control. Values were expressed either as the percentage of macrophages that were infected by *L. donovani* or as the number of amastigotes within 100 macrophages. A very significant decrease of the percentage of macrophages infected with the double targeted *TR* mutant was observed as soon as 24 hours following the infection (Fig. 5(A)). Indeed, although the infection rate was maintained throughout the experiment for the control *Leishmania* transfectant, the infection rate of the *TR/hyg* and *TR/hyg/neo* decreases steadily to reach only 12% at 72 hours (Fig. 5(A)). Similarly, the number of *L. donovani TR/hyg/neo* amastigotes per macrophage cell has drastically decreased from 15.5 amastigotes/cell at 6 hours infection to below 1 amastigote/cell after 72 hours (see Fig. 5(B)). The single *TR/hyg* mutant showed a similar phenotype with respect to intracellular survival (Fig. 5(B)). The loss of a single *TR* allele has dramatic consequences for the intracellular viability of *L. donovani*. To prove that the observed phenotype was due solely to the disruption of *TR*, we have transfected into *L. donovani TR/neo* a cosmid containing the entire *TR* gene of *L. donovani infantum*. This recombinant strain overexpressing *TR* regained completely its ability to survive inside macrophages to WT levels (Fig. 5) clearly indicating that the loss of one copy of *TR* was responsible for the decrease intracellular survival of the mutants.

To test whether the results observed in *L. donovani* would be paralleled in other pathogenic species, we have amplified a fragment of the *L. major TR* gene by PCR. The *hyg* expression cassette was cloned into the *BalI* site of the PCR fragment and this *TR-hyg* targeting construct was transfected into *L. major*. Figure 6 shows the generation of an *L. major* replacement *TR* mutant by gene targeting and its infectivity within human macrophages. Figure 6(A) Southern blot analysis of total DNAs from *L. major* WT (lane 1) and *L. major TR/hyg* (lane 2) digested with *XhoI* and hybridized to *TR* and *hyg* specific probes. Figure 6(B) shows macrophage infection *in vitro* with *L. major*. This was done as described above. The left panel corresponds to the total number of amastigotes in 100 macrophage cells and the right panel to the percentage of infected macrophages with time. ○ *L. major-neo* (control strain); □ *L. major TR/hyg*, single knockout. The average and standard deviation of four independent experiments are shown. The *XhoI* restriction sites were identical between *L. major* and *L. donovani* and upon the integration of the *hyg* gene, one *TR* allele was disrupted (9.2 kb fragment) (Fig. 6A, lane 2). Less *TR* activity was found in this mutant as it was the case for the other *Leishmania TR* inactivated mutants (Table 1). The *L. major/hyg* disruption mutant was further tested for its capacity to infect human-macrophages. As observed for *L. donovani*, the *L. major* transfectant missing one *TR* allele showed a decrease in parasite infectivity. Indeed, a sharper decrease of the infectivity was observed compared to *L. major* control transfectant and 2.5 amastigotes/cell were detected at 72 hours post-infection, a 4-fold difference with control cells (see Fig. 6B).

The phenotype of the *TR* mutants generated in this study indicate that these parasites are suitable for live vaccine development.

EXAMPLES

The above disclosure generally describes the present invention. A more complete understanding can be obtained by reference to the following specific Examples. These Examples are described solely for purposes of illustration and are not intended to limit the scope of the invention. Changes in form and substitution of equivalents are contemplated as circumstances may suggest or render expedient. Although specific terms have been employed herein, such terms are intended in a descriptive sense and not for purposes of limitations.

Methods of molecular genetics, protein biochemistry, immunology and fermentation technology used but not ex-

explicitly described in the disclosure and these Examples are amply reported in the scientific literature and are well within the ability of those skilled in the art.

Example 1

This Example describes the culturing and transfection of *Leishmania*.

The *Leishmania tarentolae* strain Tar II has been described previously (ref. 21) and the *Leishmania major* 50122 and *Leishmania donovani* 50212 strains were obtained from the ATCC. All strains were grown in SDM-79 medium (ref. 13), supplemented with 10% fetal bovine serum (FBS) (Multicell, Wisent Inc.) and 5 µg/mL of hemin. Two to 3 µg of linearized DNA from targeting constructs purified from LMP agarose (Gibco-BRL) were used for transfections into *Leishmania* cells for electroporation as described previously (ref. 14). Transfectants were selected with 40 µg/mL of G-418 (Geneticin, Gibco-BRL), or 80 µg/mL of hygromycin B (CalBiochem). Murine macrophage cell line J774, obtained from ATCC, was cultured in Dulbecco's modified Eagle's medium (D-MEM, Gibco-BRL), supplemented with 10% FBS, L-glutamine (2mM), penicillin G (100 U/ml) and streptomycin (100 µg/ml). Human peripheral blood monocytes were isolated from heparinized venous blood of normal donors by the Canadian Red Cross. Cells were centrifuged over Ficoll-Paque gradient (Pharmacia) as previously described (ref. 15). After several washes, cells were resuspended in RPMI 1640 medium (Gibco-BRL) containing 10% of human serum (Gibco-BRL). In order to differentiate monocytes into macrophages, 3 x 10⁶ peripheral blood leukocytes, counted using trypan blue, were adhered and cultured for 5 days at 37°C in 5% CO₂/95% air in a humidified atmosphere to allow for transformation. To transform *Leishmania donovani* promastigotes into amastigotes *in vitro*, the parasites were grown at room temperature in SDM medium in which HEPES were replaced by MES to adjust the pH to 5.0, and then switched overnight to 37°C in 5% CO₂ atmosphere (ref. 12).

Example 2

This Example describes techniques of recombinant DNA and the construction of targeting constructs.

A large portion of the trypanothione reductase (*TR*) coding region (85% of the *TR* gene from nucleotide 153 to 1406) from *L. tarentolae*, *L. donovani donovani TR* and *L. major* total DNAs was amplified by PCR using degenerated oligonucleotide primers derived from the *L. donovani TR* coding sequence (ref. 16). The *HpaI-SacI* PCR products (1.2kb for the *L. donovani* and *L. tarentolae* and 1.3kb for the *L. major*) were subcloned into *SacI-SmaI* sites of pSP72 vector (Promega). To make the *TR* gene knockout constructs, the neomycin phosphotransferase (*neo*) and hygromycin phosphotransferase (*hyg*) cassettes (ref. 10) were introduced as *SmaI-EcoRV* fragments into the unique *BalI*-site of the *TR* gene. For the *TR* gene of *L. tarentolae* a *neo-I-SceI* cassette was introduced instead of a *neo* cassette. A cosmid clone containing the entire *TR* coding region and flanking sequences necessary for its expression was isolated by screening a *L. donovani infantum* genomic cosmid library made in the vector CL-*hyg* (ref. 17) and gridded on high density filters with an *L. donovani TR* specific probe. The *TR* cosmid clone was transfected into *L. donovani TR/neo* single knockout strain to test for the specificity of the *TR*-mutant phenotype.

For hybridization studies, total genomic DNA from *Leishmania* was prepared as described (ref. 18), digested with *XhoI* or *EcoRI*, resolved on 0.7% agarose gels and, transferred to nylon membrane (Hybond-N, Amersham). Total RNAs from *Leishmania donovani WT* and transfectants from both promastigote and amastigote stages were prepared using Trizol (Gibco BRL). Southern and Northern blots, hybridizations and washing conditions were done following standard procedures. Intact *Leishmania* chromosomes were prepared from *Leishmania* cells harvested during mid to late log-phase, washed and lysed *in situ* in 1% low melting agarose plugs as previously described (ref. 19). For digestion of the plugs with endonuclease I-SceI the conditions used were according to the suppliers instructions (Boehringer Mannheim). The blocks were loaded directly into the wells of 1% agarose gel and sealed in place. *Leishmania* chromosomes were separated by pulsed-field gel electrophoresis using a Bio-Rad CHEF-DR III apparatus, stained with ethidium bromide, and transferred to nylon membrane for Southern blot hybridization. Blots were hybridized with radiolabelled probes prepared by randomly primed synthesis with Klenow DNA polymerase and [α -³²P]dATP. The probes used correspond to *TR*, *hyg* and *neo* coding sequences made by PCR, to the α -tubulin gene of *T. brucei* (ref. 20) and to the A2 amastigote gene (ref. 12).

Example 3

This Example describes the *in vitro* infection of macrophages.

The capacity of the *Leishmania TR* mutants to infect murine and human macrophages *in vitro* was tested in comparison to control *Leishmania-neo* transfectant, as follows. Murine and human macrophages were seeded (200 µl per well, 5 x 10⁴ cells/mL) into 8 wells chamber slides, and were infected with parasites, at a parasite to cell ratio of 20:1 for a period of 6 hours. Following this incubation, the non-engulfed parasites were removed by 3 to 5 washes with

warm medium and chambers were replenished with 500 μ L of fresh culture medium. The level of infection was determined at 6, 24, 48 and 72 hours by optical microscopy examination following Diff Quick staining of cell preparations.

Example 4

This Example describes the trypanothione reductase enzyme assay.

The preparation of cell-free extracts to measure the *TR* enzymatic activities in wild type and *TR* disrupted transfectants was done as follows. 2×10^8 *Leishmania* cells were harvested at mid to late log-phase by centrifugation. Cells were washed twice in PBS and after a second centrifugation were resuspended in 0.35 mL of freshly prepared lysis buffer (10mM potassium phosphate pH 7.2, 10 mM EDTA, 1mM DTT, 1% Triton X-100, 5 mM benzamidine, 5 mM phenanthroline, 0.1 mM phenylmethyl-sulphonyl fluoride (PMSF)). Lysis was completed by a freeze/thaw procedure repeated 3 times. TR activity was assayed spectrophotometrically by monitoring substrate dependent oxidation of NADPH at 340 nm using alanine aminotransferase as an internal control (ref. 6).

SUMMARY OF THE DISCLOSURE

In summary of this disclosure, the present invention provides novel attenuated strains of *Leishmania* in which at least one gene contributing to virulence and expressed in both the promastigote and amastigote stages of the life cycle of the strain is functionally disabled, such as by deleting at least a portion of the gene or by mutagenesis of the gene. Modifications are possible within the scope of this invention.

Table I

Trypanothione reductase (TR) activity in <i>Leishmania</i> cells				
Cells	TR genotype	TR (U/mg)	Aat ¹ (U/mg)	Ratio TR/Aat
<i>L. donovani</i>	<i>TR/TR</i>	0.212 ± 0.023	0.117 ± 0.007	1.81
<i>L. donovani</i>	<i>TR/hyg</i>	0.096 ± 0.005	0.112 ± 0.023	0.84
<i>L. donovani</i>	<i>TR/hyg/neo</i>	0.077 ± 0.016	0.097 ± 0.003	0.79
<i>L. major</i>	<i>TR/TR</i>	0.437 ± 0.041	0.337 ± 0.022	1.30
<i>L. major</i>	<i>TR/hyg</i>	0.096 ± 0.005	0.114 ± 0.002	0.84
<i>L. tarentolae</i>	<i>TR/TR</i>	0.196 ± 0.012	0.052 ± 0.008	3.77
<i>L. tarentolae</i>	<i>TR/hyg/neo</i>	0.051 ± 0.019	0.072 ± 0.003	0.71

1. Alanine aminotransferase used as an internal control.

REFERENCES

- WHO, Tropical Disease Report, 1989. pp. 85-92.
- Turco, S. J. and Descoteaux, A., 1992. The lipophosphoglycan of *Leishmania* parasites. Annu. Rev. Microbiol. 46:65-94.
- Modabber, F. 1989. Experiences with vaccines against cutaneous leishmaniasis: of men and mice. Parasitol. 98:S49-S60.
- Fairlamb, A.H., Blackburn, P., Ulrich, P., Chait, B.T and Cerami, A. (1985) Trypanothione: a novel bis (glutathionyl) spermidine cofactor for glutathione reductase in trypanosomatids. Science 227:1485-1487.
- Schirmer, R.H., and Schulz, G.E. (1987) in: Pyridine Nucleotide Coenzymes, Part B. Coenzymes and Cofactors, vol. 2, Wiley, New York, pp. 333-379.
- Shames, S.L., Fairlamb, A.H., Cerami, A., and Walsh, C.T. (1986) Purification and characterization of trypanothione reductase from *Crithidia fasciculata*, a newly discovered member of family of disulphide-containing flavo-protein reductases. Biochemistry 25: 3519-3526.
- Fairlamb, A.H., and Cerami, A. (1992). Metabolism and functions of trypanothione in the Kinetoplastida. Annu. Rev. Microbiol. 46:695-729.
- Krauth-Siegel, R.L., Enders, B., Henderson, G.B., Fairlamb, A.H., and Schirmer, R.H. (1987). Trypanothione reductase from *Trypanosome cruzi*: purification and characterization of the crystalline enzyme. Eur. J. Biochem. 164:123-128.
- Taylor, M.C., Kelly, J.M., Chapman, C.J., Fairlamb, A.H., and Miles, M.A. (1994). The structure, organization, and expression of the *Leishmania donovani* gene encoding trypanothione reductase. Mol. Biochem. Parasitol. 64:

293-301.

10. Papadopolou, B., Roy, G. and Ouellette, M. (1994). Autonomous replication of bacterial DNA plasmid oligomers in *Leishmania*. Mol. Biochem. Parasitol. 65:39-49.

11. Cruz, A., Titus, R., and Beverley, S.M. (1993). Plasticity in chromosome number and testing of essential genes in *Leishmania* by targeting. Proc. Natl. Acad. Sci. USA 90:1599-1603.

12. Charest, H. and Matlashewski, G. (1994). Developmental gene expression in *Leishmania donovani*: differential cloning and analysis of an amastigote stage-specific gene. Mol. Cell. Biol. 14:2975-2984.

13. Brun and Schönenberger (1979) Acta Trop. 36:289.

14. Papadopolou, B., Roy, G., and Ouellette, M. (1992) A novel antifolate resistance gene on the amplified H circle of *Leishmania*. EMBO J. 11:3601-3608.

15. Olivier, M., Baimbridge, K.G. and Rainer, N.E. (1992) Stimulus-response coupling in monocytes infected with *Leishmania*. Attenuation of calcium transients is related to defective agonist-induced accumulation of inositol phosphates. J. Immunol. 148:1188-1196.

16. Taylor, M.C., Kelly, J.M., Chapman, C.J. Fairlamb, A.H. and Miles, M.A. (1994). The structure, organization and expression of the *Leishmania donovani* gene encoding trypanothione reductase. Mol. Biochem. Parasitol. 64: 293-301.

17. Ryan, K.A., Dasgupta, S., and Beverley, S.M. (1993) Gene, 131:145

18. Bernards, A., van der Ploeg, L.H.T., Frasch, A.C.C., Borst, P., Boothroyd, J.C., Coleman, S., and Cross, G.A. M. (1981). Activation of trypanosome surface glycoprotein genes involves a duplication- transposition leading to an altered 3' end. Cell 27:497-505.

19. Van der Ploeg L.H.T., Schwartz, D.C., Cantor, C.R., and Borst, P. (1984). Antigenic variation in *Trypanosoma brucei* analysed by electrophoretic separation of chromosome-sized DNA molecules. Cell 37:77-84.

20. Thomashow, L.S., Milhausen, M., Rutter, W.J., and Agabian, N. (1983) Cell 32:35-43.

21. White, T.C., Fase-Fowler, F., van Luenen, H., Calafat, J., and Borst, P. (1988). The H circles of *Leishmania tarentolae* are a unique amplifiable system of oligomeric DNAs associated with drug resistance. J. Biol. Chem. 263: 16977-16983.

22. Thierry, A., Perrin, A., Boyer, J., Fairhead, C. and Dujou, B. (1991), Cleavage of yeast and bacteriophage T7 genomes at a single site using the rare cutter endonuclease I-SceI. Nucleic Acids Res. 19: 189-190.

Claims

1. An attenuated strain of *Leishmania* wherein at least one gene of the strain contributing to virulence thereof and expressed in the promastigote and amastigote stages of the life cycle of the strain has been functionally disabled.
2. An attenuated strain of *Leishmania* wherein both wild-type copies of a gene of the strain contributing to virulence thereof have been functionally disabled and a third copy of said wild-type gene is present in the chromosome of the strain.
3. The strain claimed in claim 2, wherein said gene contributing to the virulence of the strain is expressed in both the promastigote and amastigote stages of the life cycle of the strain.
4. The strain claimed in any one of claims 1 to 3, wherein at least one gene contributes to the ability of said strain to infect or survive within macrophages.
5. The strain claimed in any one of claims 1 to 4 selected from the group consisting of *Leishmania donovani*, *Leishmania braziliensis*, *Leishmania tarentolae*, *Leishmania major*, *Leishmania mexicana*, *Leishmania tropica* and *Leishmania aethiopica*.
6. The strain claimed in any one of claims 1 to 5, wherein said gene is functionally disabled by deleting a least a portion of said gene.
7. The strain claimed in any one of claims 1 to 5, wherein said gene is functionally disabled by mutagenesis thereof.
8. The strain claimed in claim 7, wherein the gene encodes trypanothione reductase.
9. An immunogenic composition comprising the attenuated strain claimed in any one of claims 1 to 8.

10. The immunogenic composition claimed in claim 9 formulated as a vaccine for *in vivo* administration to a host to confer protection against disease caused by a virulent strain of *Leishmania*.

5 11. The immunogenic composition claimed in claim 10, wherein the host is a primate.

12. The immunogenic composition claimed in claim 11, wherein the primate is a human.

13. A method of forming an attenuated strain of *Leishmania*, which comprises:

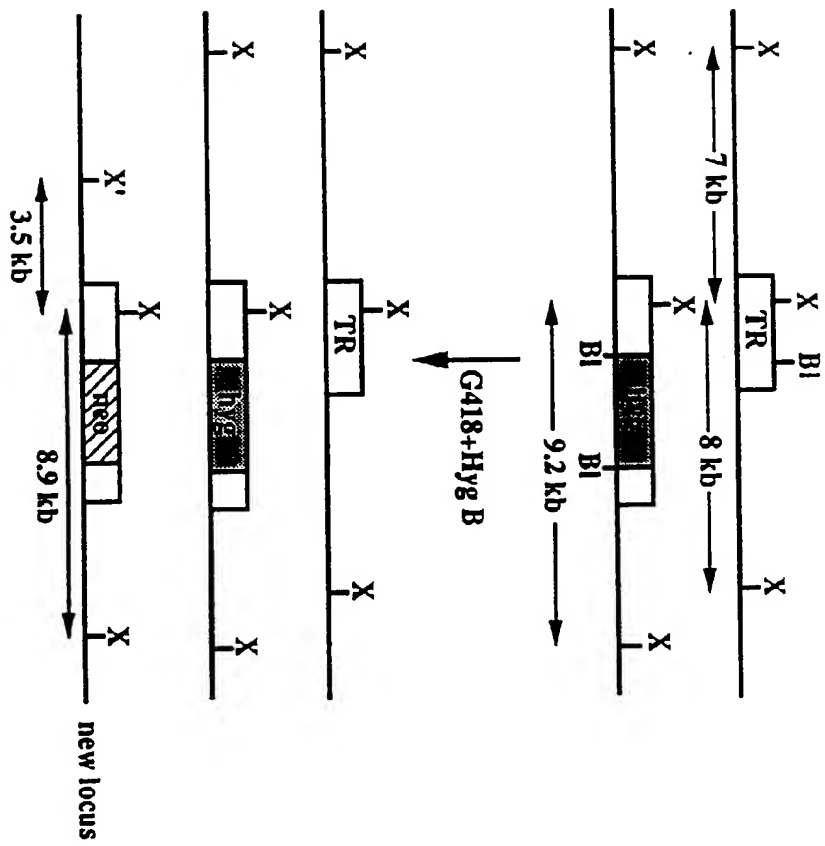
10 identifying a gene of a *Leishmania* strain contributing to the virulence thereof and expressed in both the promastigote and amastigote stages of the life cycle of the strain, and functionally disabling the gene.

14. The method claimed in claim 13, wherein said gene is functionally disabled by deletion or mutagenesis thereof.

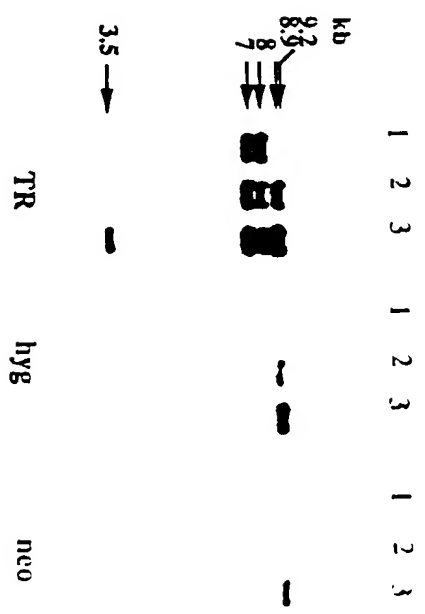
15 15. The method claimed in claim 14, wherein said gene is trypanothione reductase.

16. An attenuated strain of *Leishmania* as claimed in claim 1 or 2 when used as a medicament.

A.



B.



C.

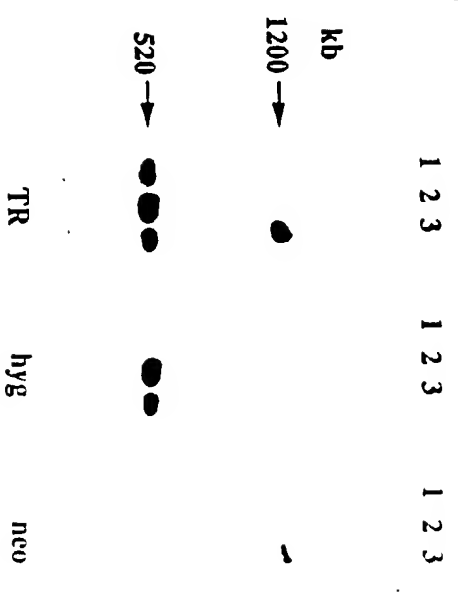
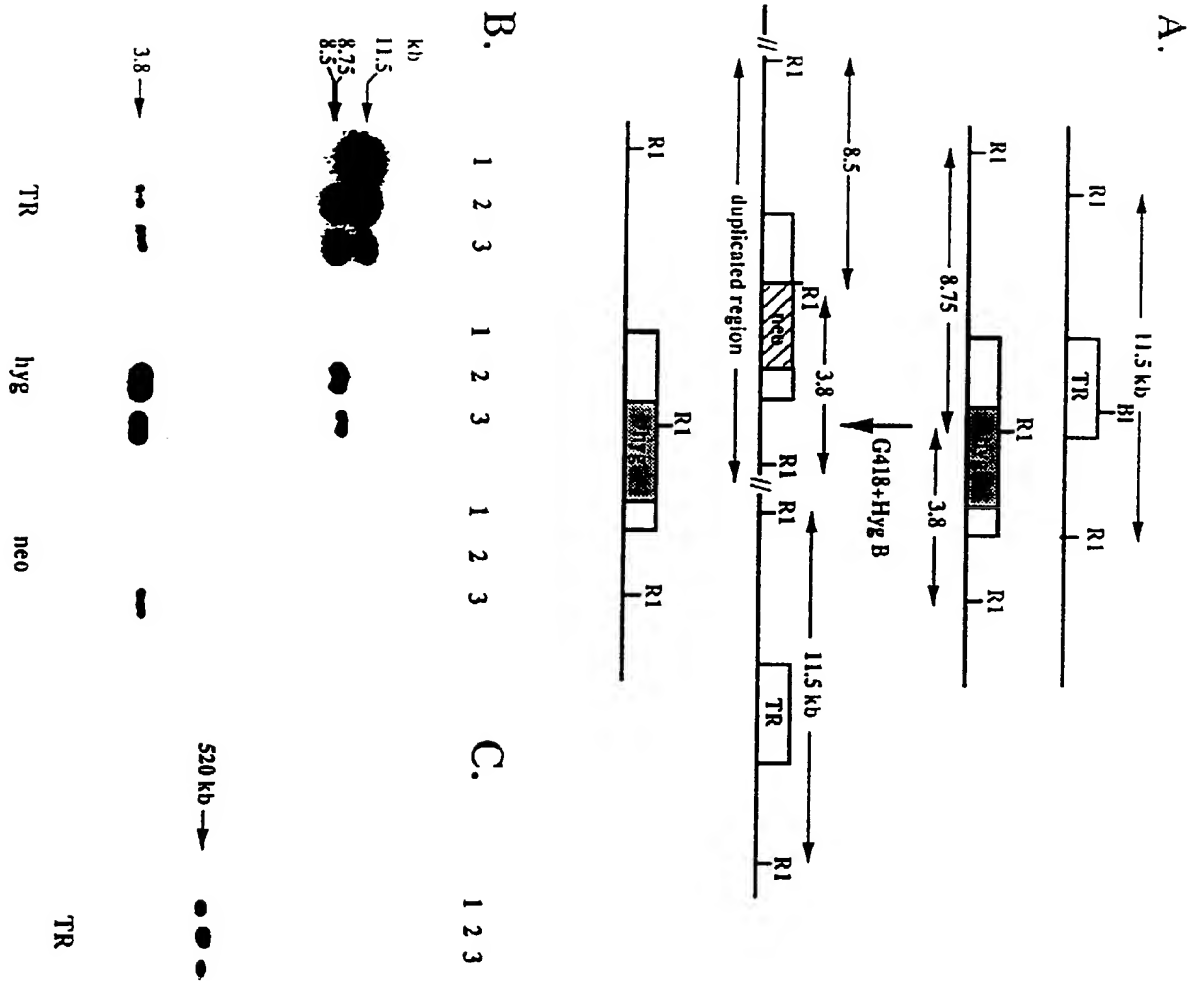


Fig. 1

Fig. 2



A.

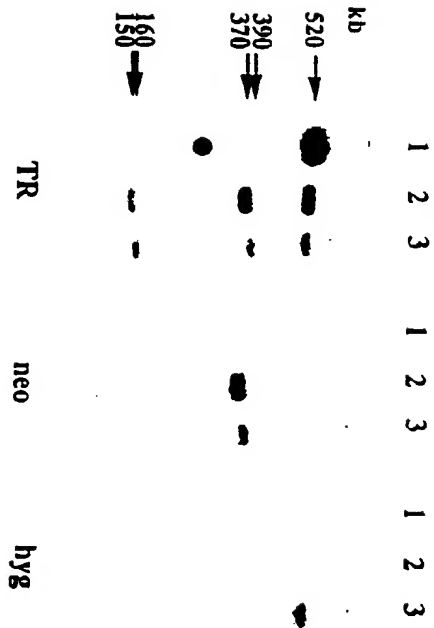
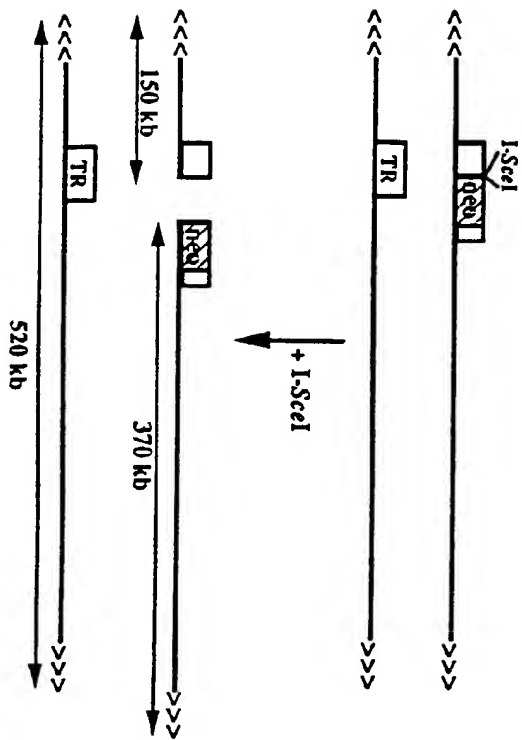
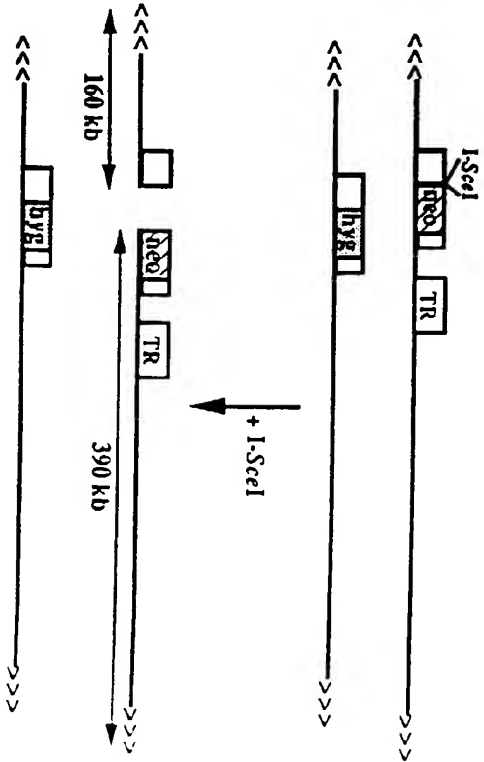


Fig. 3

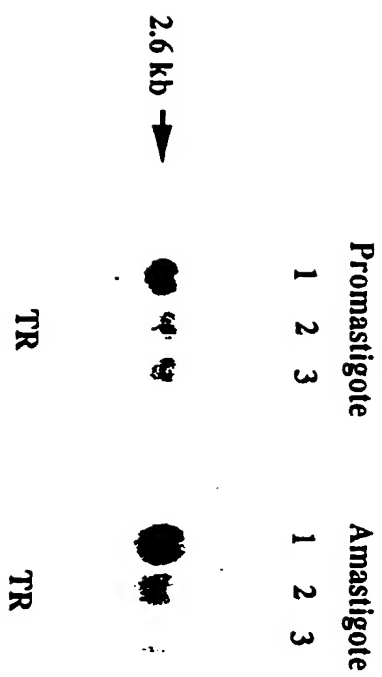
B.



C.



A.



B.



Fig. 4

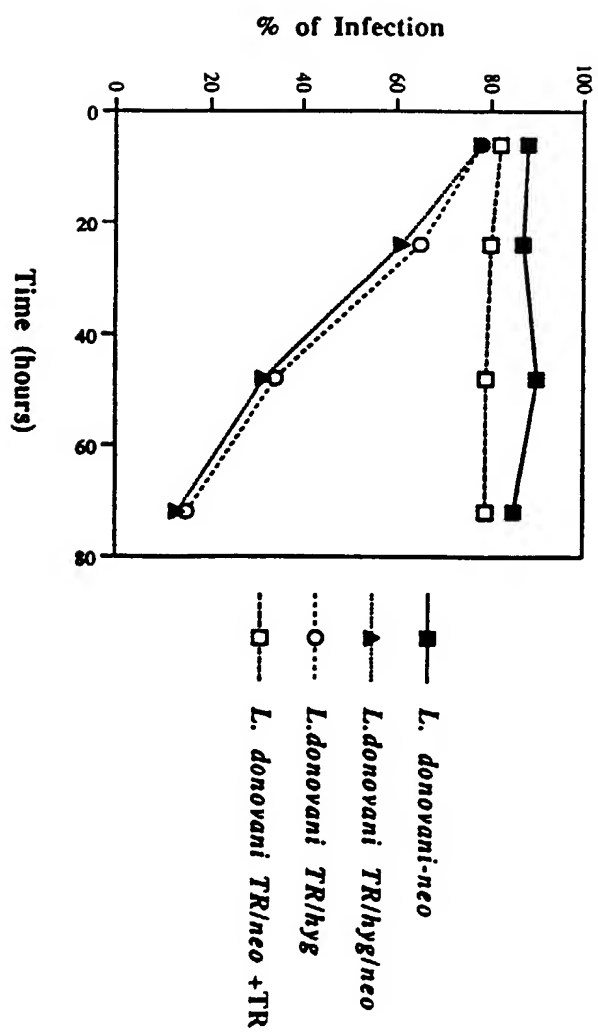


Fig. 5A

Fig. 5B

